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ANALYSIS RESULTS FROM THE LOS ALAMOS 2D/3D PROGRAM*

by

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ABSTRACT

Los Alamos National Laboratory is a participant in the 2D/3D program. Activities conducted at Los Alamos National Laboratory in support of 2D/3D program goals include analysis support of facility design, construction, and operation; provision of boundary and initial conditions for test facility operations based on analysis of pressurized water reactors; performance of pretest and posttest predictions and analyses; and use of experimental results to validate and assess the single- and multidimensional nonequilibrium features in the Transient Reactor Analysis Code (TRAC). During Fiscal Year 1986, Los Alamos conducted analytical assessment activities using data from the Cylindrical Core Test Facility and the Slab Core Test Facility. Los Alamos also continued to provide support analysis for the planning of Upper Plenum Test Facility experiments. Finally, Los Alamos either completed or is currently working on three areas of TRAC modeling improvement. In this paper, Los Alamos activities during Fiscal Year 1986 are summarized; several significant accomplishments are described in more detail to illustrate the work activities at Los Alamos.

INTRODUCTION

The 2D/3D program is sponsored jointly by Japan, the Federal Republic of Germany, and the United States (US). The safety-related objectives of the 2D/3D program are as follows.

1. To provide an improved understanding of the effectiveness of various emergency core-cooling systems (ECCS) in limiting peak fuel rod cladding temperatures during vessel refill and core reflood for medium- to large-break loss-of-coolant accidents (LOCA in pressurized water reactors (PWRs).
2. To reveal core coolant inventory and system flow characteristics during the refill and reflood phases of a medium- to large-break LOCA.
3. To study convective flow and temperature distributions inside a heated core during reflood for a medium- to large-break LOCA.

* Work performed under the auspices of the US Nuclear Regulatory Commission.

4. To assess the predictive capability of best-estimate computer codes and the conservatisms of evaluation model computer codes.
5. To obtain information which may be used to improve thermal-hydraulic models in best-estimate, evaluation-model, and other computer codes.

Activities conducted at Los Alamos National Laboratory in support of 2D/3D program goals include analysis support of facility design, construction, and operation; provision of boundary and initial conditions for test facility operations based on analysis of PWRs; performance of pretest and posttest predictions and analyses; and use of experimental results to validate and assess the single- and multidimensional nonequilibrium features in the Transient Reactor Analysis Code (TRAC).

Three experimental facilities provide data to 2D/3D program participants. The Cylindrical Core Test Facility (CCTF) is an approximately 1/21-scale facility located in Japan; this facility has completed its test program and the Los Alamos counterpart analysis program is nearing completion. The Slab Core Test Facility or SCTF is a separate-effects reflood facility also located in Japan. A full-height 1/21-scale section of the core, one fuel element wide from core centerline to outer periphery, is modeled. This facility began testing with its third electrically heated core during 1986; Los Alamos will complete analysis of Core-II tests in 1986 and will begin analysis of Core-III tests in FY-1987. The Upper-Plenum Test Facility (UPTF), located in the Federal Republic of Germany, is a 1/1-scale integral test facility focusing on phenomena in the downcomer, lower plenum, upper plenum and primary-system loops of a PWR. Los Alamos analytical efforts to date have largely supported test design and specification; posttest analyses of UPTF experiments will be started as soon as data become available.

During Fiscal Year 1986, Los Alamos conducted analytical assessment activities using data from the CCTF and the SCTF. Los Alamos also continued to provide support analysis for the planning of UPTF experiments. Finally, Los Alamos either completed or is currently working on three areas of TRAC modeling improvement. In this paper, Los Alamos activities during Fiscal Year 1986 are summarized; several significant accomplishments are described in more detail to illustrate the work activities at Los Alamos.

CCTF PROGRAM SUPPORT

We issued our summary report to document results from TRAC-PD2 (Ref. 1) analyses of the Core-I test series (Ref. 2). TRAC was able to consistently predict peak cladding temperatures that were in moderate agreement with the measured values. We define moderate agreement to mean that TRAC correctly predicted the major trends and phenomena that are dominant in determining the peak cladding temperature. Although TRAC did not predict all measured quantities uniformly well, it was able to properly characterize the parametric impact on peak cladding temperature and quench-front propagation displayed by the experimental test series.

We completed our analysis of five Core-II upper-plenum-injection (UPI) experiments and prepared a draft report summarizing our findings (Ref. 3). The objective of the UPI test series in CCTF Core-II was to investigate the effectiveness of the UPI system under a variety of boundary and initial conditions. The parameters varied were core power, core stored energy, core radial power profile, UPI flow, UPI symmetry, system pressure, and the addition of the refill phase. Associated with this objective was the desire to improve understanding of the unique characteristics of core reflood using a UPI ECCS. The phenomena included channeling of emergency core-cooling (ECC) liquid from the upper plenum into the core, multidimensional characteristics during reflood, steam binding, and negative core inlet flow.

A total of five UPI tests were performed in CCTF Core II. These tests were designed to investigate the effectiveness of the UPI ECCS under large-break LOCA conditions. Table 1 summarizes the assessment results for each of the UPI calculations. Each test was analyzed with TRAC-PF1/MOD1 (Ref. 4) to assess the predictive capability of the code and to identify model deficiencies. Because the CCTF facility is large scale, we believe that the phenomena observed during the UPI tests will also be seen in an actual PWR with UPI. Also, information is provided to support UPI-PWR licensing activities.

The TRAC predictions for four of the five UPI tests, Runs 59, 72, 76, and 78, are in overall moderate agreement with the data (Refs. 5–8). The prediction for the fifth test, Run 57 (Ref. 9), showed insufficient agreement with the data. We define insufficient agreement to mean that major trends and phenomena were not predicted correctly. A noding study was also performed on Run 57 in an attempt to increase the accuracy of the prediction. These results did not show a marked improvement. The deficiency in predicting Run 57 is not serious since the boundary and initial conditions for the test (*i.e.*, very high core stored energy, and UPI flows lower than the single-failure criteria) are outside even the most conservative assumptions for a UPI PWR. Therefore, the summary conclusions relative to TRAC applications listed below are based on the assessment activities for CCTF Runs 59, 72, 76, and 78; these are the tests with initial and boundary conditions within the achievable envelope of accident conditions in actual PWRs.

The core reflood transient for the UPI tests in CCTF Core II is characterized by strong multidimensional flows. Flow of the UPI fluid into the core is asymmetric, and tends to "channel" down one side or the other. The downward liquid flow causes local cooling of the rods and in some cases complete quench very early in the transient. This flow supplements the quench front progressing from the bottom. Steam production in the core is routed away from the channeling area in sufficient quantity to cause local complete flooding (*i.e.*, no liquid downflow). As liquid accumulates in the core, the UPI flow from the upper plenum causes the net core inlet flow to be negative. The core liquid level is established by the balance of the downcomer level and the pressure drop through the system as in the case of cold-leg injection reflood. Other features that are unique to the UPI ECCS are the pool formation and condensation in the upper plenum. Compared to a cold-leg injection configuration, the CCTF Core-II UPI results show that there is a reduction in peak cladding temperature as a result of the UPI. Although the reduction in the peak cladding temperature is small, this comparison shows that this particular alternative ECCS is equally effective as cold-leg injection.

With respect to qualitative results, we found that TRAC was consistently able to predict (1) the channeling effect, (2) the asymmetric core reflood, (3) the negative core inlet flow, and (4) the breakthrough location. In addition, the TRAC-calculated rod surface temperatures were in moderate agreement with the data. Overall, the TRAC-calculated quantitative results were sufficiently close to the data to be characterized as in moderate agreement. It is difficult to draw definitive conclusions about the impact of parametric variations for the UPI test series because more than one parameter was varied for each test. However, in general the effects of core power, core stored energy, UPI flow, and UPI symmetry were calculated.

The overall effectiveness of the UPI ECCS was assessed by comparison to a CCTF Core-II cold-leg-injection experiment of similar power and stored energy. The test results show that a slight reduction in the peak cladding temperature occurs as a result of the UPI. TRAC is able to predict this trend. Although the reduction in peak cladding temperature is slight, the results show that the UPI provides adequate core cooling during the assumed accident conditions.

As a consequence of our UPI assessment activities, several improvements in the TRAC code have been requested. These are (1) modeling of condensation in the cold leg, (2) prediction of liquid downflow rate from the upper plenum into the core, (3) prediction of core void fraction distribution in the region of vapor upflow, and (4) entrainment/deentrainment in the upper plenum (related to the flow regime map implementation). With respect to item 1, improvements to the condensation model are planned to be released with TRAC-PF1/MOD3. For item 2, a CCFL option has been incorporated in TRAC-PF1/MOD1 with EC 12.9. For items 3 and 4, improvements in the core void distribution and entrainment/deentrainment will be included in TRAC-PF1/MOD2 (late FY 87 release). For one study, we also examined the relationship between noding practice and the prediction of breakthrough location. We found that for very low UPI flows, a much finer noding (doubling of azimuthal sectors from four to eight) was required to produce a moderate agreement in breakthrough location. User guidelines have been summarized and recommendations made with respect to the noding detail and the UPI input model.

TRAC is able to predict the major phenomena associated with UPI reflood transients and quantitatively predict the rod temperatures. An important TRAC capability is the ability to model and predict the important multidimensional flows that occur in UPI facilities during reflood transient. It is believed, therefore, that to adequately represent the dominant reflood phenomena, a multidimensional prediction capability is required. We believe that TRAC-PF1/MOD1 can be used with confidence to predict UPI transients in actual plants assuming sufficient detail is incorporated in the facility input model.

We also completed our analysis of Run 71 (Ref. 10), the single best-estimate test run in the CCTF. Significant phenomena observed in this test included long-period hydraulic oscillations in the core which caused overcooling of the lower core and dryout and reheat of the upper levels of the core. TRAC also predicted core oscillations but with a shorter period and smaller amplitude. TRAC predictions of average peak cladding temperatures, heater rod behavior in the lower levels of the core, and overall loop pressure drop were in moderate agreement with measurements.

SCTF PROGRAM SUPPORT

We prepared our summary report to document results from TRAC-PD2 analyses of the Core-I test series (Ref. 11). This test series showed that the impacts of radial power peaking and "hot channel" factors are mitigated by multidimensional hydrodynamics resulting in a "chimney" cooling effect in the high-power bundles. For this series, TRAC-PD2 was able to accurately predict both the hydrodynamic and heat-transfer phenomena during the core reflood phase. In particular, there was moderate agreement between the predicted and measured peak cladding temperatures under blind posttest conditions for a spectrum of parametric experimental tests. We have completed one operational study using TRAC-PF1/MOD1 in support of the initial phase of SCTF Core III testing.

We have completed a detailed study of the SCTF upper-plenum liquid accumulation with special-purpose TRAC input models. Typically, for cold-leg injection-type reflood transients in SCTF, we have underpredicted the amount of liquid accumulation and its distribution in the upper plenum (Fig. 1), and the amount of liquid accumulation in the hot leg. To investigate the reason for this difference, we developed a stand-alone model of the upper plenum, and imposed steam and liquid boundary conditions that were developed from the experimental data. Although there is a large uncertainty in the data for the amount of liquid exiting the core, we found that given these conditions, the prediction for the upper-plenum liquid accumulation was in much better agreement with the data (Fig. 2). From this result, we concluded that the upper-plenum deentrainment was predicted reasonably well by TRAC, and that the reason for the previous difference between the prediction and the experiment for the amount of upper-plenum liquid accumulation was the lack of liquid carryover from the core region

To investigate the reason for the upper-plenum liquid distribution that is observed in the data (Fig. 1), we did a series of noding studies with our stand-alone upper-plenum model. We found that with sufficiently fine noding we could obtain a distribution of liquid in the upper plenum similar to the experimental data. We determined that the distribution was at least partially caused by the Bernoulli effect (velocity pressure-lift effect), which occurs as the vapor velocity increases as it enters the hot leg from the upper plenum.

To investigate the reason for the underprediction of liquid accumulation in the hot leg, we developed a stand-alone input deck for this component, and imposed boundary conditions in a method similar to that used in the upper-plenum study. The SCTF hot-leg geometry is atypical of reactor hardware since it is rectangular in geometry, 0.116 m wide and 0.737 m tall. In contrast, the constitutive relations used in TRAC were developed from circular-pipe data. Thus, as a parametric study, we modified the constitutive relations for the interfacial drag. We found that changes to the interfacial drag model in TRAC had a very small effect on the deentrainment results. The largest effect occurred when the slip ratio for the inlet conditions was increased. We believe, therefore, that this is an area that requires further examination, caused by the nonprototypical geometry of the SCTF upper plenum and hot leg. Care must be taken in drawing conclusions regarding the predictive capability of TRAC.

UPTF PROGRAM SUPPORT

During this period, we continued to provide support analysis for the planning of UPTF tests. Although actual tests have been completed in the facility, the test data are not yet available and therefore posttest analyses have not been attempted. To date we have completed the pretest analysis of three planned tests in the facility that are of special interest to the US participants: (1) a downcomer separate effects test (DC-SET), (2) a small break LOCA hot-leg counter-current flow limitation (CCFL) test, and (3) a US/Japan (J) PWR large-break LOCA integral test. Work also continued on improving the input decks for the facility. Improvements include the modeling of the subcooled injection system recently added to the facility and the addition of the nitrogen-injection systems to the intact-loop ECC-injection nozzles.

Analysis of the possible loads on the instruments in the facility is receiving special attention. In light of the recent damage to the drag disks in the loops and the degradation of many of the instrument signals, increased efforts are being made to avoid further potential damage. In working closely with consultants from MPR Associates Inc., we have identified the potential for damage to the downcomer level detectors in the upcoming DC-SET tests. Possible alternatives are being assessed to mitigate this potential.

In the case of the hot-leg CCFL test, the comparisons against a set of possible correlations is acceptable. Also, the instrument loads are well within the limits of the facility. Thus, this particular test is expected to yield useful data, and not cause any operational problems.

For the US/J integral test, a procedure was developed for the start of the test that will meet the target values for several system parameters. Since this test is initiated at a high system pressure of 10–18 bar, the facility will blow down to containment pressure after the opening of the break. The pretest calculation was continued for the reflood portion of the transient as well. The results show that the test can be run successfully without exceeding facility limits.

TRAC-PF1/MOD1 IMPROVEMENT ACTIVITIES

We have either completed or are currently working on three areas of model improvement. First, we have added a CCFL model to the code. Thus far, we are seeing significant improvements in the comparison to tie-plate flooding data for the saturated injection case and the subcooled injection case. Second, we have added the capability to connect more than one PIPE or TEE to one VESSEL cell. Multiple-source connections provide a marked improvement in modeling capability, and was used successfully in the completion of the UPI test analyses. Finally, we are in the process of adding a separator model that will include liquid carryover and vapor carry under as a function of mixture flow rate and quality. The user will provide these data to the code in the input.

Future development activities will address improvements in the prediction of the core void distribution and entrainment during reflood, the prediction of direct contact condensation, and the prediction of deentrainment.

SUMMARY

We believe that Los Alamos is functioning as a vital participant within the 2D/3D Coordination Program. The results of our analytical efforts are being used to support test specification and design, improve understanding of phenomena occurring in tests, assess the predictive capability of TRAC, and identify needed areas of code improvement.

TABLE 1

CCTF-UPI-ASSESSMENT SUMMARY

Run	Type		Results
72 (C2-13)	No failure Symmetric Injection	Overall Agreement:	• Moderate
		Predicted:	• Multidimensional reflood • Negative core inlet flow • Location of liquid downflow • Rod temperatures
		Deficiencies:	• Excessive condensation of ECC fluid in cold legs • Overprediction of amount of down-flow
76 (C2-16)	Single failure, single point injection	Overall Agreement:	• Moderate
		Predicted:	• Multidimensional reflood • Negative core inlet flow • Rod temperatures (average values)
		Deficiencies:	• Excessive condensation of ECC fluid in cold legs • Overprediction of amount of down-flow • Location of downflow • Void distribution in core
78 (C2-18)	Single failure low power, stored energy	Overall Agreement:	• Moderate
		Predicted:	• Multidimensional reflood • Negative core inlet flow • Location of liquid downflow • Rod temperatures (average values)
		Deficiencies:	• Excessive condensation of ECC fluid in cold legs • Overprediction of amount of down-flow • Void distribution in core
59 (C2-AS1)	Single failure, Asymmetric injection	Overall Agreement:	• Moderate
		Predicted:	• Multidimensional reflood • Negative core inlet flow • Rod temperatures (average values) • Amount of downflow
		Deficiencies:	• Excessive condensation of ECC fluid in cold legs • Exact location of downflow

TABLE 1 (cont)

CCTF-UPI-ASSESSMENT SUMMARY

Run	Type		Results
57 (C2-AA1)	80% single failure, asymmetric injection, high power, stored energy	Overall Agreement:	• Insufficient
		Predicted:	• Multi dimensional reflood
		Deficiencies:	• Overprediction liquid entrainment into hot legs and steam binding • Overprediction of amount of liquid downflow • Location of liquid downflow • Core water accumulation

REFERENCES

Note: Reports in the LA-2D/3D-TN series contain proprietary data from the Japan Atomic Energy Research Institute (JAERI), which cannot be released to a third party without authorization from the US NRC and JAERI.

1. Safety Code Development Group, "TRAC-PD2: An Advanced Best-Estimate Computer Program for Pressurized Water Reactor Loss-of-Coolant Accident Analysis," Los Alamos National Laboratory report LA-8709-MS, NUREG/CR-2054 (April 1981).
2. F. Motley, "Research Information Report Results From TRAC Analysis of Cylindrical Core Test Facility Core I Test Series," Los Alamos National Laboratory document LA-2D/3D-TN-86-10 (July 1986).
3. M. W. Cappiello, H. J. Stumpf and B. E. Boyack, "CCTF Core II UPI Summary," Los Alamos National Laboratory document LA-2D/3D-TN-86-16 (to be issued).
4. Safety Code Development Group, "TRAC-PF1/MOD1: An Advanced Best-Estimate Computer Program for Pressurized Water Reactor Thermal-Hydraulic Analysis," Los Alamos National Laboratory report LA-10157-MS, NUREG/CR-3858 (July 1986).
5. M. Cappiello, "CCTF Run 59 TRAC-PF1/MOD1 Analysis," Los Alamos National Laboratory document LA-2D/3D-TN-85-1 (January 1985).
6. M. W. Cappiello, "TRAC-PF1/MOD1 Analysis of CCTF No-Failure UPI Test C2-13 (Run 72)," Los Alamos National Laboratory document LA-2D/3D/TN-86-7 (July 1986).
7. H. J. Stumpf, "CCTF Run 76 TRAC-PF1/MOD1 Analysis," Los Alamos National Laboratory document LA-2D/3D/TN-86-6 (to be issued).
8. H. J. Stumpf, "CCTF Run 78 TRAC-PF1/MOD1 Analysis," Los Alamos National Laboratory document LA-2D/3D/TN-86-5 (to be issued).
9. B. E. Boyack, "TRAC-PF1/MOD1 Analysis of CCTF UPI Test C2-AA1 (Run 57)," Los Alamos National Laboratory document LA-2D/3D-TN-86-11 (to be issued).
10. H. J. Stumpf, "CCTF Run 71 TRAC-PF1/MOD1 Analysis," Los Alamos National Laboratory document LA-2D/3D-TN-86-8 (to be issued).
11. K. A. Williams, "Research Information Report on the Experimental and Analytical Results of the Core-I Test Series at the Japan Atomic Energy Research Institute Slab Core Test Facility," Los Alamos National Laboratory document (to be issued).
12. P. R. Shire and B. E. Boyack, "TRAC Analysis of Upper Plenum Thermal-Hydraulic Phenomena in the Slab Core Test Facility," to be published in the Transactions of the ANS, 1986 Winter Meeting, Washington, D. C. , November 16–20, 1986.
13. J. C. Lin, "TRAC-PF1/MOD-1 Calculation of SCTF Core-II Test S2-SH2 (Run 605)," Los Alamos National Laboratory document LA-2D/3D-TN-85-15 (March 1985).

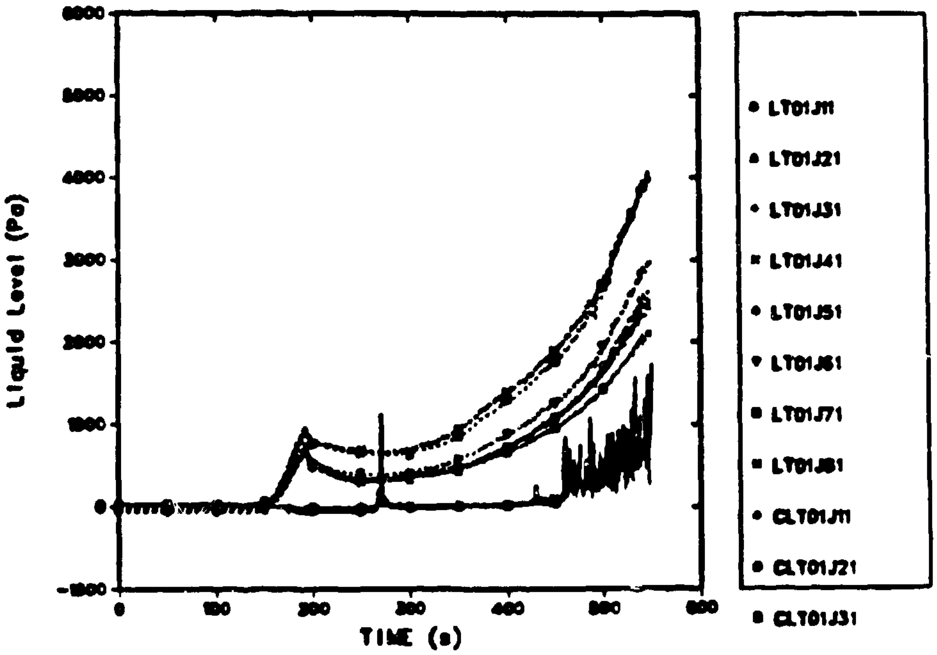

Fig. 1.
Upper-plenum liquid level calculated for SCTF Run 605 using the full-facility model.

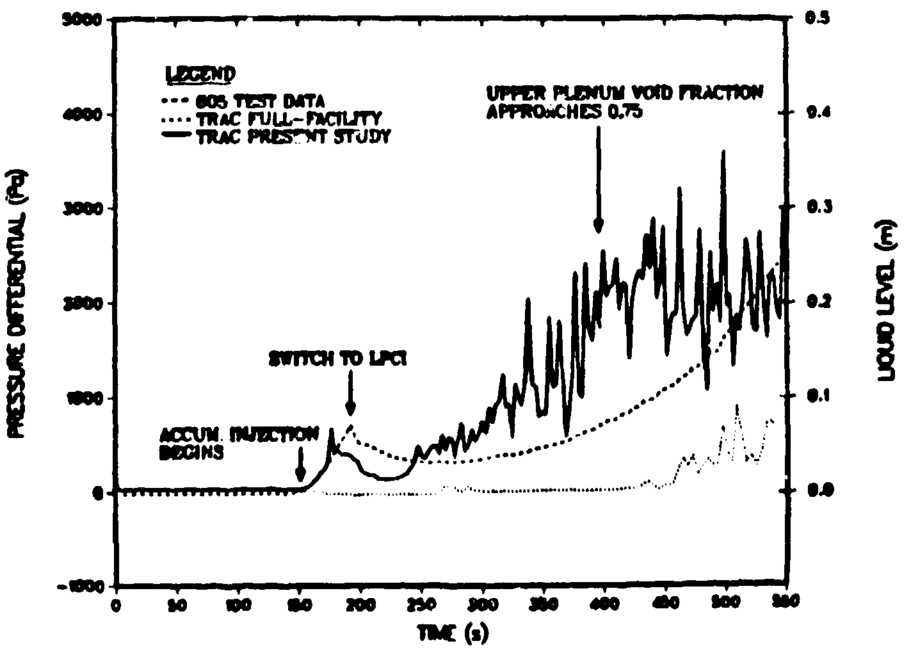

Fig. 2.
Upper-plenum liquid level calculated for SCTF Run 605 using the stand-alone upper plenum model.